

Polarized RF Gun meeting Notes 11/7/05

Attendees:

Hans Bluem - Advanced Energy Systems
Tony Favale – Advanced Energy Systems
John Lewellen – ANL
Ilan Ben-Zvi (absent) – BNL
Vladimir Litveninko – BNL
David Yu – DULY Research Inc.
Don Edwards – FNAL
Helen Edwards – FNAL
Ray Fliller – FNAL
Grigory Kazakevich – FNAL
Sergei Nagaitsev – FNAL
Mike Syphers – FNAL
Alexander (Sasha) Shemyakin – FNAL
Matt Poelker – JLAB
Manouch Farkhondeh – MIT BATES
Court Bohn – NIU
Kirk McDonald – Princeton
Axel Brachmann – SLAC
Jym Clendenin – SLAC
Greg Mulhollan – Saxet Surface Science

Program:

Helen gave a brief introduction to the meeting, listing the meeting goals and the problem to be solved.

Jym then gave an overview of SLAC activities and his concerns for installing a GaAs cathode in an RF gun.

After the lunch break, Tony gave an overview of AES activities on a 700 MHz $\frac{1}{2}$ cell SRF gun to be used for RHIC e-cooling and testing for the navy.

Vladimir gave an overview of BNL SRF gun plans.

This was followed by (and interleaved with) discussions.

Notes: What follows is some synthesis of the Ray Fliller's meeting notes. They should not be regarded as "meeting results", but more as topics discussed. It is very likely that I have missed a topic or two. Please email Ray for if there is an omission.

Major Problems with GaAs cathodes in RF guns:

1. Vacuum quality (with and without RF)
2. Ion back bombardment
3. Vacuum quality
4. Electron back bombardment (unique to RF guns)
5. Field emission from cavity

6. Vacuum quality
7. Photons???

Proposed Guns:

1. Cryo cooled Normal Conducting 1 ½ cell gun (AES/BNL SBIR-expired)
2. Normal Conducting HOM gun (Saxet/SLAC SBIR)
3. Superconducting ½ cell gun (AES/BNL/FNAL SBIR)
4. Normal Conducting 1+2/2 cell PWT gun (DULY/ FNAL SBIR)

Tests to be performed to demonstrate cathode:

1. Dark lifetime in gun without RF needs to be on order of years.
 - a. “Or else you will be in trouble”
2. Dark lifetime in gun with RF needs to be “a long time”
3. Operational lifetime needs to be operationally acceptable
 - a. “Depends on what you need to fix it”
 - b. Mean time between cesiations
 - c. Time to change cathode
4. Initial measurements of QE, dark current, bunch charge, emittance, polarization
5. Start making steps toward ILC source parameters

Simulations to perform

1. Ion bombardment (source, flux, energy)
 - a. differences between Lewellen and Bluem simulations for 1.6 cell gun
2. Electron bombardment (source, flux, energy)

SLAC/SAXET plans

1. Simulations of bombardment
2. Build L band gun, either HOM or PWT as proof of principle
3. Keep the ILC in mind
4. Contingent on SBIR

AES/BNL/FNAL/MIT plans

1. AES builds 700 MHz ½ cell SRF gun
2. AES (?) Test gun for Navy
3. Deliver gun to BNL for RHIC e-cooling
4. MIT BATES makes the GaAs cathode
5. FNAL does work to produce magnetized beam
6. BNL does work on elliptical bunch shaping
7. Design 1.3 GHz 1 ½ cell SRF gun for FNAL SMTF.

DULY/FNAL plans

1. Duly designs and builds a 1 + 2/2 cell PWT, load lock, and prep chamber.
2. FNAL does simulations of round and magnetized beam dynamics.
3. Testing with a GaAs cathode.

4. Beam parameter measurements

What follows is are notes of the meeting discussion kept by Ray Fliller. This is barely condensed version of his notes. He has decided to err on the side of wordiness and longevity to encompass the entire discussion and to ensure that no stone is left unturned on the discussion.

Meeting starts with Helen's introduction.

The problem at hand is **to produce an RF gun capable of supporting an NEA GaAs cathode for polarized electron beam production**. The "holy grail" is to produce a gun that could serve as an injector for the ILC without the electron damping ring.

The goals of the meeting are:

1. Identify the critical issues
2. gather information on plans
3. outline future plans for
 - a. Normal conducting RF guns
 - b. Superconducting RF guns
 - c. PWT guns
 - d. DC guns
4. list proposals and make a preliminary list
5. plan for continued activities

Jym's presentation of his ideas and concerns for normal conducting guns of all types:

Jym: 90% polarization achieved with DC guns, 95% may be achievable.

DC gun limits:

1. SLAC gun: 120 kV, 1.8 MV/m field
2. SLAC FEL: 300 kV, 3 MV/m field using a GaAs cathode
3. Nagoyo: 200 kV, guesses 2-2.5 MV/m field
4. Sinclair wants 700kV, 30 MV/m field (!)

L band guns cannot reach these extraction voltages. Max is 40 MV/m @ cathode with a 20 MV/m effective gradient.

Matt: JLab has no problems at 350 kV, but things are unstable at 420 kV. This is blamed on Cs on the cathode ball. Wei Gai may have an L band gun with >40 MV/m cathode gradient.

Jym: Lower voltage DC guns need a buncher to match into the RF structure. At higher voltages, this may not be a problem. Cortoni at DESY did work on a TESLA design to not use a buncher. Jym is not sure how high a voltage you need. Pulsed DC guns can do higher voltages than CW.

Helen: Shifting the discussion back to RF guns, at high Peak field, Klystrons may be a limit, especially for long pulse operation.

Jym: The 5 MW klystron at DESY shows that a 1.6 cell gun can do the ILC job. Have to design the gun around the cathode however! Remember, in a DC gun the cathode can be difficult about 100 kV. RF guns also have electron back bombardment. There is still the Novosibirsk experiment.

Greg: Electron energy matters. Few eV to keV secondary electrons can mediate reactions by breaking bonds. MeV electrons can destroy the GaAs structure.

Don: Simulations show about 100 keV electron energy for back bombardment.

John: Field emission can be large and heat the cathode. A vertical B field may help, but may also hurt beam quality.

Grigory: In an S band system saw 20-30 keV back bombardment. A 1kG transverse field was used to deflect. Also observed UV photons.

Jym: SLAC wants to do simulations for electrons and ions. May actually do a controlled bombardment experiment, but only once gas species and energies are known.

Manouch: Even then, we'd still like to know that actually happens on the surface.

David: Simulating electron bombardment gives the relation between Epeak and phase. There is an advantage to low field here.

Jym: We can lower the field to compensate back bombardment.

Vladimir: 20-30 MV/m cathode field in SRF guns is typical.

Jym: The advantages of RF guns are a simpler injector and a smaller 6D emittance. It may also be that the RF gun is not done in time for the ILC. DC guns can do the transverse emittance, but not the longitudinal.

Matt: So use a buncher.

Helen: Don't forget, we have to make the RF gun work in the first place!

Jym: UV may help distinguish species. Using an RGA, how do you know what is really in the gun? Tomizawa Appl. Surf. Sci. 235 (2004) 214. KEK experiment on materials, using HIP copper and got 40 uA at 40 MV/m. Yoshioka at Linac 94. Also focus on vacuum pumping. Sheffield PAC 93, 2970 and (something I can't make out).

David: A PWT for high vacuum was never built.

Jym: Holes can increase the conductance by 80x. Prep can help outgassing and certainly wan NEG pumps. KEK sees not difference in RGA with and without RF in the above experiment.

Helen: Heating and cooling may be a problem with holes.

David: PWT gun does not have this problem.

Jym: John's HOM gun shunt impedance drops a factor of 2 for same field.

Helen: There were differences in John's ion bombardment simulations and Hans'.

Hans: Found lower bombardment than John. Also did not find ion coming from second cell, may be do to geometry differences.

Jym: Vacuum is typically 1e-12 torr in a DC gun. Lifetime is several days between cesiations.

Helen: An RF gun may be different.

Jym: This however is different than the ion issue.

Greg: There are essentially two problems. One is the static background pressure. The other is the ion bombardment.

Helen: Electrons are unique to the RF gun. Ions may be less important.

John: 10 keV is typical impact energy for ions.

Greg: Then sputtering effects should dominate.

Helen: What about Contamination??

Jym: Oxides! H2O, O2, CO2 are main worries for copper.

Matt: Carbons are likely an issue since heat cleaning cannot remove them. Carbons are cleaned with H gas cleaning. Remember that carbons need "lightning" to be deposited.

Jym: Have to process gun to hearts delight. CERN used Cs2Te cathode and saw no effect in S-band gun.

Ray disappeared for a minute: When he returned....

Jym?: Transmission mode operation of cathode gives higher QE.

Tony: Will use 70K operating temp for the SRF gun cathode.

Jym: Good. Thermal emittance is lower. Doping should not be higher than $1e18$ for a 100 nm cathode. A 600um GaAs cathode looks like metal to RF, a thin cathode likely looks like a hole because of larger skin depth.

Matt: Typical dark lifetime (lifetime in static conditions, occasional illumination for monitoring purposes) is on order of years.

Manouch: Otherwise you are in trouble from the start.

Jym: RF lifetime needs to be “A long time”.

Helen: It depends on what needs to be done to fix the cathode.

Jym: Quick list of other issues: input coupler (Side. Vs. coaxial, vs. dual side), material (OFHC Cu vs. HIP Cu.), Single Crystal, load lock issues – vacuum in particular, cleaning issues, high temperature bake, cathode plug design (choke or close fitting – this is a field emission area), crystal holder design.

John: Thermionic guns have similar issues. AET(?) gun wall have depression into cathode port. The cathode sits behind the gun wall, the depression acts like a spring. Field emission is no problem at 80 MV/m. Or make a TM010 mode in cathode cell and put joint at zero crossing.

Jym: Thermal Emittance is 0.1 mm-mrad max for $\sigma_{max}=1mm$ with A PEA cathode. NEA is 2x higher. Andreas Wolf at Heidelberg/ Max Plank institute. What about another cathode? Like one that works! Try a higher band gap III-V semiconductor that would need a UV laser. Would also need stress. QE could be 50%, but what about polarization. This would work well in poor vacuum, but they have never been made stressed before.

Sergei: Sasha Alexandrov says that some photo emitted electrons may take a long time to exit the cathode.

Greg?: MITES group sees 8 ps FWHM emission time with thin cathode.

Sergei: May be longer with thick cathode. This is a source of secondary emission that has not been mentioned.

Jym: This is a separate issue. Photo absorption depth is on order 1 um.

Sergei: Reducing field emission is necessary but not sufficient according to Alexandrov.

Jym: Field emission is not an issue in his opinion.

Sergei: This is function of affinity, 0 is best.

Kirk: The high QE may not be worth NEA.

Jym: How do you control the work function?? Cs alone can get you to 0 affinity.

Greg: Plain Cs surface is vulnerable.

Jym: K is more stable. Cs-K perhaps??

Greg: The theory is K is more stable because the atoms are smaller and can be more closely packed. The heavier the alkali, the better the QE.

Lunch break.

Afternoon session starts with Tony Favale giving his talk on the AES SRF gun work with various government entities.

Tony: AES has 2 Navy contracts for a 1A current, 700 MHz, 1/2 cell, SRF gun. AES has contract for prep chamber and transport tray. BNL, JLAB, John Lewellen involved with

Navy contracts. BNL gets the gun in 2007 for RHIC e-cooling use. The advantages of the AES design is the ultra high vacuum inherent to SRF, the versatile cathode prep system – including the ability to place a magnet in the gun choke, a low Bfield area (the plan is for less than 1 kG). This gun is overkill for ILC, AES considers the ILC gun to be an easier design.

Sergei: A uniform B field is absolutely necessary for flat beam production.

Tony: Gun has 2 – 1 MW side input couplers. They have the ability to bias the cathode for bombardment issues. The prep chamber will be done in 07 and is in collaboration with Pat O'Shey of U. Maryland. AES gun designed so that no field emission from iris will hit the cathode.

Jym: What are the limits of SRF?

Helen: Surface B field in theory, and field emission practically. Can the static B field be constructed so that it is repelled.

David: Why SRF and not use normal conducting cavity and cryogenically cool it?

Ray: Liquid N2 cooling showed that the vacuum does not improve that much when cooled to 90K. No cryopumping is seen. The effect at 90K is the collect the residual gas in the gun volume forming a lower temperature, lower pressure, denser gas than at room temperature. Some gasses freeze out like CO2. For cryopumping to occur, the vapor pressure of the gasses needs to drop, this does not start to happen until 20-30 K is reached.

Vladimir: The ultimate vacuum also depends on initial conditions.

Vladimir Litveninko now outlines BNL's plans for the 700MHz SRF gun.

Vladimir: Plans for the SRF gun under the SBIR with AES. 1) Test the QE and the lifetime in the SRF gun. 2) Flat beam production with FNAL. 3) Elliptically shaped beams for good emittance. 4) Design a 1.5 cell gun for SMTF (beyond SBIR). BNL is interest in non-magnetized e-cooling based on Recycler success.

Sergei: Notes that the smaller of the ILC emittances is 0.3 mm-mrad.

Vladimir: Discussed the idea of swapping the low longitudinal emittance with the higher (but not by much) horizontal emittance. The simulations he shows use an elliptical distribution. Showed a simulation of a 160G static B field inside the SRF choke which is repelled by the superconductor. Responding to a question noted that the cathode radius is 6 mm. For a discussion of the ellipsoidal shape see Cecile Limberg-Deprey 2005 FEL conference. He also showed the BNL-ERL.

Helen: Gun diagnostics??

Vladimir: Notes that transverse B field for magnetic mirror will destroy the emittance. The zigzag injection is designed for diagnostics, and leaves 4m. In response to question notes that smallest spot size is current density limited (cathode effect).

Manouch: This is an ultimate limit.

Matt: JLab has not yet gotten that far.

David Yu now outlines DULY's design of a PWT

David: Outlines design of a 1+2/2 cell (half cell at each end) PWT gun operating at 20 MV/m. A similar S band gun is installed at UCLA with a vacuum of 1e-9 torr.

However, no effort was placed into lowering the vacuum beyond this. Notes that a 7 + 2/2 cell was discussed at Snowmass.

Helen: Why is PWT different?

David: Vacuum. PWT is an open structure so it is possible to use NEG and SNEG pumping to achieve ultra high vacuum. Philippe Piot did simulations with a PWT gun at 20 MV/m and 2 cryomodules showing a 3 mm-mrad round beam emittance for 0.8 nC. Higher gradient did not lower emittance. Electrons at the iris do not hit cathode.

Jym: Notes that iris design may not be critically important.

Helen: Assumed that cathode was field emission point.

David: Shows simulation of emission from cathode holder. Discussed pumping schemes for vacuum performance and vacuum calculations. Use a stainless steel vessel to house the gun. Stainless is outside of the RF field so the conductance is not an issue. The gun structure is made with stainless rods coated with copper. Showed design of load lock and prep chamber design. Noted that the 7+2/2 cell requires 136 kW average power, uses 2-10MW Klystrons! Also showed thermal design of the gun.

Grigory: What is the frequency stability of the gun.

David: Not an issue.

At this point discussion ensued, Ray tries to keep the highlights.

Jym: See the web page for the Nanobeam workshop. Don't forget the Rossendorf SRF work. There is a normal conducting design, 3 1/2 cell with the last cell containing a magnetic mode for emittance compensation. SLAC has an ILC polarized source web site. Worried about how to continue, last time we dropped the ball. We should develop a list of R&D goals.

Kirk/Helen: University funding sources.

Helen: SBIR is most likely route for labs.

Jym: Polarized RF gun source is on the DOE SBIR list. This is good! SLAC ILC department see R&D starting in 2007.

Don: Fermi should have higher interest now.

Jym: Suggests a workshop every year or so. Maybe a PAC session.

Don: Notes that ILC is far enough in the future that BCD can be separate from R&D efforts.

Helen: What are SLAC's plans?

Jym:

- Proposal for normal conducting gun with Saxet.
- No commitment if gun will be HOM or PWT. Prefer HOM.
- L band station
- Simulations of ion bombardment
- Goal is proof of principle gun, with ILC in mind.
- If no SBIR, this work is put off.

Tony: SBIR's require that only one non-profit lab can participate and receive 30% of the funds in phase I.

Helen: Can we list the warm and cold gun issues?

Response: Simulation understanding is important. Normal conducting guns may work as the source of ions may not be too bad, but electrons are an open question.

John: If vacuum is good, ion flux is likely not an issue, if dark current is low, x-rays won't be either.

Jym: What is the mechanism for the pressure rise with RF, it is not just processing. HIP copper necessary. It may not be critical, but it is hard to get.

Helen: Do we expect dark current from the cathode?

Jym: No. There is a uniform surface and (almost) no electrons in conduction band. High polarization cathodes are thin, so the late emission issue is not a concern. Wonders aloud if we could put a thin cathode in the Budker gun?

Vladimir: Can we make the bunch train? Worried about charge density issue.

Axel: SLAC will make an ILC laser for DC gun in next 2 years. This will not be a short pulse picosecond laser.

Jym: SLAC has achieved the charge density in long pulse operation.

Manouch: MIT BATES plans to work with BNL on the cathode side of things.

Helen: So for now we have no answer to charge density issues. Her take on SRF is that oxidation is not an issue, nor is ion bombardment, unless stuff is expelled from surface, and the cathode operating at a higher temp than the gun is a good thing.

Jym: Higher polarization may result from 77K operation.

Greg: 4K will freeze out the charge carriers. 77K not an issue.

Jym: Designing the cathode may be an issue.

Tony: AES has a design.

Manouch: Heat cleaning is needed.

Tony: Can happen with their design. Notes that SNS has huge field emission problem (1kRad/m), and no effect on vacuum seen. Unsticking stuff from surface should not be a problem.

Kirk: The cathode could still be hit.

Vladimir: We can operate at lower gradient.

Tony: Simulations show that stuff coming from the iris cannot hit the cathode.

John: Don't forget, we must design the gun around the cathode. The SLAC guns have not been optimized in this way. Even if the gun needs to be a terrible gun as far as RF is concerned (low shunt impedance, etc.) to get a cathode test done.

Jym: Notes CsKSb has lifetime issues in bad vacuum. If CsKSb survives will in an SRF gun, then GaAs may be more promising.

Kirk: If the Cs in CsKSb is on the surface, we can learn a lot!

Tony: BNL has a 1.3 GHz, 1/2 cell SRF gun with an RF choke. WE will know something about CsKSb next summer.

Vladimir: Lists BNL's immediate plans:

- Move to building 912
- Test multipactoring in SRF gun
- Test cathodes in same gun.

Helen: Lists Don's activities for SRF:

- Polarized cathode in gun.
- Polarized electron measurement
- Cathode insert
- Magnetized beam
- Elliptical profile
- Simulation work

Vladimir: BNL wants to do the elliptical profile work. Would like FNAL on Magnetized beam.

Helen: Agreed, also FNAL do beam dynamics work.

There is some discussion of the elliptical bunch shaping.

Don: Don't forget the Eindhoven work.

Helen: what is BNL's laser pulse structure?

Vladimir: 3MHz min, 9MHz preferred.

Tony: MIT BATES makes the cathode.

Manouch: We have polarimeter too.

Helen: Polarization measurement is likely later on.

Jym: Laser pulse shaping is also low on the list. Magnetized beam can be done on other cathodes.

Grigory: GaAs cathodes in PMT's have 1000 hour life for the last 40 years, need to do the RF test.

Jym: Need to pass the no RF test first.

Helen closes the meeting. Discussion for a future meeting. Considerations:

- SLAC people may not be able to make a large meeting (competition).
- Workshop format??
- Meet after SBIR award are announced??